Onderzoeksrapport Nr. 7901

TECHNOLOGY CHOICE AND REVENUE REQUIREMENTS REGULATION

by

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Wettelijk Depot : D/1978/2376/35.

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I. Introduction

Public utility prices are typically adjusted through an administrative rate review proceedings involving data submission by the utility, commission staff evaluation, and public hearings. The criteria and methods used to determine the appropriate level of prices, and particularly the structure of prices, are often imprecisely stated, if they are stated at all, and seem to depend on economic, social welfare, and political considerations. Empirical studies, such as those of Joskow (1972) and Hagerman and Ratchford (1978), have provided insight into the determinants of the allowed rate of return for utilities, and the models analyzed by Sibley and Bailey (1978) have a similar focus on the difference between a firm's actual return and its target rate of return. A regulatory commission's focus on the allowed or target rate of return seems natural, and that rate is the principal factor governing the magnitude of a price change.

Price changes occur at the initiation of either the regulatory commission or more frequently by the regulated firm. Administratively, a firm will, for example, file with the commission a new tariff effective at a specified date, and the commission will then suspend the tariff pending administrative review. Evaluation of the new tariff and public hearings take place during a processing period or lag[1] at the end of which the new tariff goes into effect or, as is usually the case, the commission directs the firm to file a new tariff with specified prices or with prices that are estimated to yield the allowed rate of return.

Many commissions determine the appropriate prices based on a "revenue requirements" approach in which prices are determined to provide sufficient revenue to permit the firm to earn its allowed rate of return on its rate base or capital stock. This approach is described and analyzed by Robichek (1978) and essentially involves estimating the operating costs of the firm and adding to that figure the total allowed return on capital determined by multiplying the approved rate base by the allowed rate of return. The operating costs can be estimated for either a current or a future "test year".

The purpose of this paper is to analyze a firm's choice of technology when it anticipates a factor price change and a subsequent price adjustment based on a current test year, revenue requirements approach. Since the firm's choice of technology affects both its operating costs and its rate base, incentive or moral hazard problems are created that bias the choice of technology. When a factor price increase is anticipated, two incentive problems are involved. First, since the firm recognizes that an output price increase will be granted as a consequence of a factor price increase, the firm has an incentive to choose a technology that favors that factor input. Second, if the firm is allowed to earn a return on its rate base that exceeds the cost of capital, the firm has an incentive to employ more capital relative to other factor inputs as in the Averch-Johnson (1962) model.[2] As will be demonstrated, the first effect dominates and undercapitalization results for allowed rates of return close to the cost of capital, while for higher allowed rates the second effect dominates and overcapitalization results. The regulatory authority can thus use the allowed rate of return to achieve its regulatory objectives and will prefer to set the allowed rate of return at a level such that either technical efficiency or overcapitalization results.

A currently employed alternative to administrative rate review procedures is an automatic adjustment formula such as that used by the New Mexico Public Service Commission (1975) for adjustment in prices for the Public Service Company of New Mexico.[3] The Commission stated

> "... this order allows and provides for automatic, quarterly adjustments in these base rates hereafter where the accounting reports of the company demonstrate that, during the preceding accounting period, PNM's earned "rate of return on the book value of its common equity capital" (ROE) allocable to jurisdictional electric service, after deduction for all other costs of such service, is above or below a specified range on either side of an allowed rate of return."

The most widely use automatic adjustment formulae are the fuel adjustment clauses employed in electricity pricing that pass on as adjusted output prices changes in the cost of boiler fuels.[4] As Baron and De Bondt (1978a, 1978b) indicate, these clauses can involve incentive problems resulting in the choice of a technology that employs too much fuel relative to capital when fuel prices are anticipated to increase.

Automatic adjustment mechanisms have been adopted primarily because of the long processing period associated with administrative rate reviews. This period varies among jurisdictions with an average of approximately 10.5 months in 1974 according to the Edison Electric Institute (reported in U.S. House of Representatives (1975, p. 112)). Proponents of automatic adjustment mechanisms argue that the rapid adjustments of output prices are necessary to enable utilities to maintain financial viability and to raise capital. Opponents, however, point out that the adverse effects on a firm's financial strength can also be diminished by the use of future test periods, interim rate relief or by a reduction in the length of the processing period.

While an administrative rate proceeding necessarily involves a lag, there is some evidence that the length of that lag may be to some extent controllable by a commission. For cases decided between January 1, 1976 and March 31, 1977, the average processing lag was approximately 7.5 months for the seven states that do not use fuel adjustment mechanisms, and only in Washington did the processing lag approach the 1974 average (see Appendix A). The shorter lag in these states may be due to relatively less complex cases or to a lighter commission workload, but the data suggest that commissions may be able to take steps to reduce the processing lag. Earlier predictions suggest however that a reduction of the lag may promote inefficiency and aggravate incentives towards overcapitalization [Baumol and Klevorick (1970), Bailey and Coleman (1971)]. In this paper it will be shown that under a revenue requirements approach a reduction of the processing lag will result in an increase in the fuel-capital ratio when the allowed rate of return is set close to the cost of capital. When the allowed rate is sufficiently above the cost of capital the opposite result obtains.

The model is introduced in the next section and a characterization of the efficiency of the firm's chosen technology is given in Section III. The effect of the allowed rate of return and the length of the processing period on the technology choice is examined in Section IV, and the results are discussed in the final section.

II. The Model

The model utilized is intended to be general enough to capture the principal features of lagged revenue-requirements regulation and yet be sufficiently simple to facilitate the analysis and to make the results more transparant then they would be otherwise. The focus is on a utility that must choose its fuel-capital ratio in light of an anticipated change in relative factor prices at some uncertain future date. Once the factor prices have changed, a rate review is initiated by the authority or by the firm and a processing period or lag ensues. At the end of this period price is adjusted according to the revenue requirements approach. The time frame for this process is analogous to that used in Baron and De Bondt (1978a) to investigate the effect of a fuel adjustment clause, and a comparison of these two regulatory alternatives is presented in the final section.

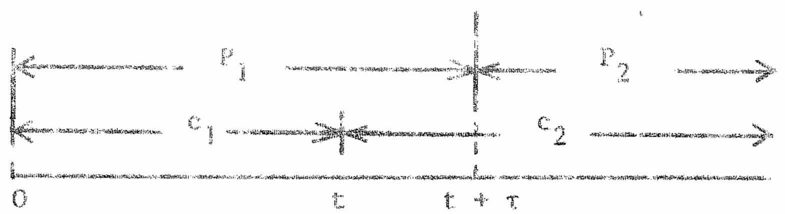
At time 0 when the firm makes its technology decision, the output price is P_1 and the factor price of fuel is c_1. The firm may be thought of as anticipating a relative scarcity of fossil fuels and hence that the factor price of fuel will change to a known level c_2 at some uncertain date t in the future.[5] To represent the timing of the factor price change, let $F(t)$ denote the probability that the factor price has not changed prior to time t. The conditional probability density function of a price change at time t, given that it has not changed prior to t, is $k(t) = F'(t)/(1 - F(t))$, which is referred to as the hazard rate in reliability theory. For simplicity it is assumed that the hazard rate $k(t) = k$, a constant, which implies that $F(t) = 1 - \exp(-kt)$. The hazard rate is assumed to be exogenous to the firm as is the magnitude of the factor price change.

In response to the factor price change, a regulatory review is immediately initiated and continues during a processing period of length τ at the end of which a new output price P_2 is set by the authority. The processing period τ is assumed to be of known duration in order to simplify the analysis, and while this may be a good description of the regulatory process in some states such as Illinois, where decisions are typically rendered close to the legal maximum of eleven months, it may be a poor assumption for other jurisdictions.[6] Once the price P_2 is set, it remains in effect thereafter, since the factor price c_2

remains constant. The timing aspects of the model and the corresponding notation are summarized in Figure 1.

Figure 1

Time Frame and Notation



The production possibilities of the firm will be represented by a simple putty-clay technology involving two inputs : capital and fuel. At time zero the firm can freely choose its technology, characterized by the fuel-capital ratio, but once that ratio has been determined, it cannot be altered. The ex-ante production function is specified as homothetic, with output Q_i in period i given by $Q_i = H[G(K_i,f_i)]$, where H is a strictly increasing function and G is a strictly increasing production function that is homogeneous of degree one. Applying the inverse φ of H and dividing by K_i yields

$$\varphi(Q_i)/K_i = G(K_i,f_i)/K_i = G(1,\gamma) \equiv 1/g(\gamma),$$

where γ is the fuel-capital ratio and g is strictly decreasing in γ, since G is strictly increasing.

The firm is assumed to be required to satisfy demand, and the ex post fuel and capital inputs required to meet demand $Q(P_i)$ are determined by the fuel-capital ratio chosen ex ante. The inputs are given by

$$K_i(Q_i,\gamma)= g(\gamma)\varphi_i, \quad i = 1,2$$

$$f_i(Q_i,\gamma) = K_i(Q(P_i),\gamma) = \gamma g(\gamma)\varphi_i, \quad i = 1,2,$$

where $\varphi_i \equiv \varphi(Q(P_i))$ and $Q_i \equiv Q(P_i)$. Consequently, once the fuel-capital ratio has been determined ex ante, the ex post inputs are constrained to lie on a ray in the (K,f)-plane. The profit earned by the firm is given by

$$\pi_1 = P_1Q(P_1) - c_1f_1 - vK_1 = P_1Q_1 - \varphi_1M_1 \qquad \text{for } [0,t)$$
$$\pi_2 = P_1Q_1 - \varphi_1M_2 \qquad \text{for } [t,t+\tau)$$
$$\pi_3 = P_2Q_2 - \varphi_2M_2 \qquad \text{from } t+\tau \text{ on,}$$

where v is the real cost of capital and $M_i = c_i\gamma g(\gamma) + vg(\gamma)$ is the cost per unit of φ_i.

The new price level P_2 is assumed to be determined on a "current test year, revenue requirements" basis under which the price is set to keep the firm "whole" given the factor price c_2 or equivalently given the unit cost M_2. The revenue requirement is the current operating costs $\varphi(Q(P_2))(c_2\gamma g(\gamma) + vg(\gamma))$ plus the allowed return $sK_2 = s\varphi(Q(P_2))g(\gamma)$, where $s \geqslant 0$ is the allowed excess rate of return. Under the revenue requirements approach the price is set to provide sufficient revenue to cover this requirement, so P_2 satisfies[7,8] $\pi_3 = sK_2$ or

$$P_2Q(P_2) - \varphi(Q(P_2))[c_2\gamma g(\gamma) + (v+s)g(\gamma)] = 0 \qquad (1)$$

The firm is realistically assumed to know that the authority employs the revenue requirements approach and hence is able to determine the effect of its choice of technology on the price P_2 through the implicit relationship in (1). The revenue requirements approach thus incorporates a moral hazard or price influence effect that will be analyzed in more detail in the following section. In order to focus on this effect, the initial price P_1 is assumed to be fixed.

The objective of the firm is assumed to be the maximization of expected discounted profits V given by

$$V = \int_0^\infty F'(t)\left[\int_0^t e^{-rt_o}\pi_1 dt_o + \int_t^{t+\tau} e^{-rt_o}\pi_2 dt_o + \int_{t+\tau}^\infty e^{-rt_o}\pi_3 dt_o\right]dt,$$

where r is the discount rate and π_3 is constrained by ( ). Integrating with respect to t_0, substituting $F(t) = 1 - e^{-kt}$ and integrating with respect to t, yields :

$$V = [r\pi_1 + k(1 - e^{-r\tau})\,\pi_2 + ke^{-r\tau}\pi_3]/r(r + k). \tag{2}$$

The value of the firm is thus a linear combination of the profits π_1, π_2, and π_3 with the weights depending on the discount rate, the hazard rate, and the length of the processing period. The value V will be assumed to be strictly concave in γ.

The above setting essentially reduces to the Bailey-Coleman treatment of lagged rate of return regulation [Bailey and Coleman (1971)] when k approaches infinity. In their framework the production technology is chosen in a stationary environment [10] with the choice of technology triggering the price revision. In the present model it is the factor price change and the resultant change in the actual rate of return for an already chosen technology that causes the administrative rate of review process to commence.

III. Revenue Requirements Regulation and Technical Efficiency

Since revenue requirements regulation involves a dependence of the price P_2 on γ, the technical efficiency of the firm's technology choice is affected by regulation. The optimal fuel-capital ratio γ^* satisfies

$$-r\varphi_1\partial M_1/\partial\gamma - k(1 - e^{-r\tau})\varphi_1\partial M_2/\partial\gamma + ke^{-r\tau}d\pi_3/d\gamma = 0, \tag{3}$$

where

$$\frac{d\pi_3}{d\gamma} = \frac{\partial\pi_3}{\partial P_2}\cdot\frac{\partial P_2}{\partial\gamma} + \frac{\partial\pi_3}{\partial\gamma} = \frac{\partial\pi_3}{\partial P_2}\cdot\frac{\partial P_2}{\partial\gamma} - \varphi_2\partial M_2/\partial\gamma.$$

The technical efficiency of the optimal fuel-capital ratio can be investigated on both an _ex post_ and an _ex ante_ basis. _Ex post_ efficiency requires that at any point in time the marginal rate of technical substitution equals the negative of the factor price ratio. For the technology considered here the *ex post* technically efficient ratios γ_1 and γ_2, satisfy

$$\partial M_1/\partial\gamma = c_1[g(\gamma_1) + \gamma_1 g'(\gamma_1)] + vg'(\gamma_1) = 0 \quad \text{for } 0 \leq t_o < t \tag{4a}$$

and

$$\partial M_2/\partial\gamma = c_2[g(\gamma_2) + \gamma_2 g'(\gamma_2)] + vg'(\gamma_2) = 0 \quad \text{for } t_o \geq t, \tag{4b}$$

where $-(g(\gamma_i)+\gamma_i g'(\gamma_i))/g'(\gamma_i)$ is the marginal rate of technical substitution. *Ex post* efficiency cannot be satisfied at all instants when $c_2 \neq c_1$ since the fuel-capital ratio cannot be adjusted *ex post*, so *ex post* technical inefficiency is necessarily present. Other firms, regulated or unregulated, with the same technology would also operate with *ex post* inefficiency, so the best that can be achieved is *ex ante* efficiency.

The *ex ante* efficient fuel-capital ratio is designated by $\gamma_o = \gamma_o(\tau, P_1, P_2)$ and satisfies

$$[-r\varphi_1\partial M_1/\partial\gamma - k\varphi_1\partial M_2/\partial\gamma + ke^{-r\tau}(\varphi_1 - \varphi_2)\partial M_2/\partial\gamma] = 0. \tag{5}$$

The fuel-capital ratio γ_o thus minimizes the expected cost of producing output $Q(P_1)$ until $t + \tau$ and output $Q(P_2)$ from then on. A special case of γ_o occurs when $P_2 = P_1$ in which case the last term in (5) is zero. The ratio $\gamma_a \equiv \gamma_o(\tau, P_1, P_1)$ thus minimizes the cost of producing an output $Q(P_1)$ and will be referred to as the "constant output" efficient fuel capital ratio. The following proposition relates γ_o, γ_a, and the *ex post* efficient ratios.

Proposition 1 : The *ex ante* efficient ratio $\gamma_o(\tau, P_1, P_2)$ has the following properties for $c_2 > c_1$, $P_2 > P_1$, and $0 < k < \infty$:

1) $\gamma_1 > \gamma_o > \gamma_a > \gamma_2$, 2) $\partial\gamma_o/\partial\tau < 0$, 3) $\lim_{\tau\to\infty} \gamma_o = \gamma_a$, and 4) $\partial\gamma_o/\partial P_2 > 0$.

The firm would adopt γ_a if it expected price, and hence output, to remain unchanged even though the fuel price increased from c_1 to c_2, since γ_a balances the costs of employing too little fuel at factor prices c_1 (relative to γ_1) and too much fuel at the factor price c_2 (relative to γ_2). With a higher price ($P_2 > P_1$) after $t + \tau$, the output Q_2 is less than Q_1, so a ratio γ_o higher than γ_a is employed. As τ increases, the price increase is delayed, and in the limit γ_o approaches γ_a from above.

The regulated firm however does not face a constant price, but instead a price adjustment occurs at time $t + \tau$. The chosen ratio γ^* will still be <u>ex ante</u> efficient provided $\frac{\partial \pi_3}{\partial P_2} \frac{\partial P_2}{\partial \gamma} = 0$ as is indicated by comparing (3) and (5), so the firm does not deviate from minimizing expected cost provided the adjusted price P_2 is the preferred price ($\partial \pi_3/\partial P_2 = 0$) or it is imposed or viewed as exogenous ($\partial P_2/\partial \gamma = 0$). In either case a price increase would result in the choice of a larger fuel-capital ratio (i.e., $\partial \gamma_o/\partial P_2 > 0$) than if there were no price adjustment, since with the price increase a smaller output level will need to be produced and hence the marginal cost at the higher fuel price is reduced. Similarly the larger the processing period τ the longer the firm will have to supply the greater output, and consequently less fuel relative to capital will be employed (i.e., $\partial \gamma_o/\partial \tau < 0$) in order to reduce expected cost.

A firm however knows that the new price P_2 will be determined according to the revenue requirements approach which creates an incentive, represented by $\partial P_2/\partial \gamma$, to attempt to influence P_2 by the choice of technology. This incentive problem can result in the adoption of a technology that is biased from the corresponding expected cost minimizing choice γ_o. If regulation is effective in restraining price below the level that the firm would set for its chosen technology, i.e., $\partial \pi_3/\partial P_2 > 0$, regulation will be said to be "effective", and in this case, the direction of the ex ante bias is indicated by the sign of $\partial P_2/\partial\gamma$. The following proposition establishes the nature of the bias.

Proposition 2 : The optimal choice γ^* with effective regulation is larger (smaller) than the corresponding ex ante efficient choice $\gamma_o(\tau, P_1, P_2^*)$ as $\partial P_2/\partial\gamma|_{\gamma^*, P_2^*}$ is greater (smaller) than zero.

This prediction is also relevant for price adjustment methods other than the revenue requirements approach. For example, a fuel adjustment clause allows increases in fuel cost to be passed on according to a formula representing the change in average fuel costs, which for the model considered here has the form $P_2 = P_1 + (c_2 - c_1)\varphi_1 g\gamma/Q_1$ and hence $\partial P_2/\partial\gamma > 0$ if $c_2 > c_1$, since $g + \gamma g' > 0$. Such clauses thus induce the adoption of more fuel-intensive technologies than those which would minimize expected cost at the same prices.

The bias is more complicated under the revenue requirements approach because the sign of $\partial P_2/\partial\gamma$ is ambiguous a priori. Implicit differentiation of (1) yields

$$\frac{dP_2}{d\gamma} = \frac{\varphi_2 \partial M_2/\partial\gamma + \varphi_2 sg'}{\partial\pi_3/\partial P_2 - \varphi_2' Q_2' sg} = \frac{\varphi_2(c_2(g + \gamma g') + (v + s)g')}{\partial\pi_3/\partial P_2 - \varphi_2' Q_2' sg}, \tag{6}$$

which has the sign of the numerator, since the denominator is positive when regulation is effective. Letting γ_2^s be the fuel-capital ratio satisfying (4b) with v replaced by v + s, strict convexity of $M_2(v + s) \equiv (c\gamma g + (v + s)g)$ implies

Proposition 3 : When regulation is effective, the adjusted price is increasing (constant) (decreasing) in γ at γ^* as $\gamma^* > (=) (<) \gamma_2^s$. Proposition 2 thus implies that $\gamma^* > (=) (<) \gamma_o$ as $\gamma^* > (=) (<) \gamma_2^s$.

To interpret this result, consider a γ greater than γ_2^s and note that a further increase in the fuel-capital ratio increases the unit cost M_2, and hence increases $M_2(v + s)$. A higher price P_2 is thus needed to cover this increase. For $\gamma < \gamma_2^s$ an increase in γ reduces $M_2(v + s)$ permitting a lower adjusted price. The direction of the bias caused by revenue requirements regulation thus depends on the relationship between γ^* and γ_2^s.

This relationship will be investigated in more detail in Section V, but first a further characterization of γ^* will be given by investigating the marginal post-adjustment profit $d\pi_3/d\gamma$ at the optimal γ^*. The results are summarized as

Proposition 4 : If regulation is effective in the post-adjustment period, the following results obtain : (a) At the optimal fuel-capital ratio γ^*, $d\pi_3/d\gamma = 0$ if $s = 0$ and $d\pi_3/d\gamma < 0$ if $s > 0$. (b) If $s = 0$, $\gamma^* > \gamma_a$ for all τ and $\lim_{\tau \to \infty} \gamma^* = \gamma_a$. (c) $\gamma_1 \geq \gamma^*$ for all $s \geq 0$ and $\gamma_1 > \gamma^*$ for $\tau > 0$. If $\tau = 0$ and $s = 0$, $\gamma^* = \gamma_1$.

Proof : (a) Evaluating $d\pi_3/d\gamma$ yields using (6)

$$\frac{d\pi_3}{d\gamma} = \frac{\partial\pi_3}{\partial P_2}\frac{dP_2}{d\gamma} + \frac{\partial\pi_3}{\partial\gamma}$$

$$= \frac{\partial\pi_3}{\partial P_2}\left(-\frac{\frac{\partial\pi_3}{\partial\gamma} - \varphi_2 sg'}{\frac{\partial\pi_3}{\partial P_2} - \varphi_2'Q_2'sg}\right) + \frac{\partial\pi_3}{\partial\gamma}$$

$$= -\frac{\partial\pi_3}{\partial\gamma}\left(\frac{\varphi_2'Q_2'sg/(\partial\pi_3/\partial P_2)}{1 - \varphi_2'Q_2'sg/(\partial\pi_3/\partial P_2)}\right) + \frac{\varphi_2 sg'}{1 - \varphi_2'Q_2'sg/(\partial\pi_3/\partial P_2)} . \qquad (7)$$

If $s = 0$, $d\pi_3/d\gamma = 0$, and for $s > 0$, the last term in (7) is negative if regulation is effective ($\partial\pi_3/\partial P_2 > 0$). In that case the first term is negative (zero) (positive) as $\partial\pi_3/\partial\gamma = -\varphi_2 \partial M_2/\partial\gamma$ is negative (zero) (positive). Since $\partial\pi_3/\partial\gamma|_{\gamma=\gamma^*}$ is negative (zero) (positive) as $\gamma^* >$ (=) (<) γ_2, a sufficient but not necessary condition for $d\pi_3/d\gamma < 0$ when $s > 0$ is $\gamma^* \geq \gamma_2$. If $\gamma^* < \gamma_2$, $\frac{\partial \pi_3}{\partial \gamma} = -\varphi_2 \frac{\partial M_2}{\partial \gamma} > 0$.

Also, $\frac{\partial M_2}{\partial \gamma} > \frac{\partial M_1}{\partial \gamma}$, since

$$\frac{\partial M_2}{\partial \gamma} - \frac{\partial M_1}{\partial \gamma} = (c_2 - c_1)(g + \gamma g') > 0,$$

so

$$0 > \frac{\partial M_2}{\partial \gamma} > \frac{\partial M_1}{\partial \gamma} .$$

Then, if $d\pi_3/d\gamma \geq 0$, all three terms in (3) are positive which contradicts the optimality of γ^*. Hence, $d\pi_3/d\gamma < 0$ for any γ^*.

(b) To compare γ_a and γ^* for $s = 0$, note that $d\pi_3/d\gamma = 0$ implies that the first-order condition for γ^* in (3) reduces to

$$-r \frac{\partial M_1}{\partial \gamma} - k(1 - e^{-r\tau}) \frac{\partial M_2}{\partial \gamma} = 0.$$

This expression differs from that for γ_a by the presence of the term $(1 - e^{-r\tau})$, and since $\gamma_1 > \gamma_a > \gamma_2$ from Proposition 1, $\frac{\partial M_2}{\partial \gamma}\Big|_{\gamma = \gamma_a} > 0$. Consequently,

$$\left[-r \frac{\partial M_1}{\partial \gamma} - k(1 - e^{-r\tau}) \frac{\partial M_2}{\partial \gamma} \right]\Big|_{\gamma = \gamma_a} > 0 \quad \text{for } \tau < \infty ,$$

so $\gamma^* > \gamma_a$ if $s = 0$. Examination of (3) indicates immediately that $\lim_{\tau \to \infty} \gamma^* = \gamma_a$ if $s = 0$.

(c) To compare γ^* and γ_1, note that evaluated at γ_1, (3) is

$$\frac{\partial V}{\partial \gamma}\Big|_{\gamma = \gamma_1} = -k(1 - e^{-r\tau})\varphi_1 \frac{\partial M_2}{\partial \gamma} + ke^{-r\tau} \frac{d\pi_3}{d\gamma} .$$

The first term $(-k(1 - e^{-r\tau})\varphi_1 \frac{\partial M_2}{\partial \gamma})$ is nonpositive, since $\gamma_1 > \gamma_2$ implies that

$\frac{\partial M_2}{\partial \gamma}\Big|_{\gamma = \gamma_1} > 0$. The second term is nonpositive from part a), so $\frac{\partial V}{\partial \gamma}\Big|_{\gamma = \gamma_1} \leq 0$.

Consequently, $\gamma_1 \geq \gamma^*$ for all $s \geq 0$. If $\tau > 0$, $\frac{\partial V}{\partial \gamma}\Big|_{\gamma = \gamma_1} < 0$ and $\gamma_1 > \gamma^*$. ∎

Proposition 4 indicates that the firm will for any allowed excess return s choose a fuel-capital ratio that is less that the ratio γ_1 which is efficient at the lower factor price c_1. The firm thus responds "in the correct direction" to the factor price change by reducing γ below γ_1. For $s = 0$, $\gamma_1 > \gamma^* > \gamma_a > \gamma_2$, but for $s > 0$ it is possible that the fuel-capital ratio is less than the constant output efficient ratio γ_a and even smaller than the ex post efficient ratio γ_2 after the factor price change. This results because of a desire to decrease the fuel-capital ratio in order to increase the capital input K_2 employed after the output price change and hence to increase the return sK_2. When the allowed return is positive but small, the firm employs a ratio that is less than that which minimizes expected cost over the pre-adjustment period (until $t + \tau$) and greater than that which maximizes profit during the post-adjustment period. The firm thus balances the marginal profit effects in the pre- and post-adjustment periods.

An alternative interpretation of part (a) of Proposition 4 follows from noting that $\pi_3 = sK_2$, so $d\pi_3/d\gamma = sdK_2/d\gamma$, which establishes the following Corollary.

Corollary : If $s = 0$, $dk_2/d\gamma$ is indeterminate. If $s > 0$ and $\gamma^* \geq \gamma_2$, $dK_2/d\gamma < 0$. The firm thus employs less capital than would maximize expected profit in the post-adjustment period because of the desire to employ more fuel relative to capital in the $[0,t)$ period.

An increase in the hazard rate k corresponds to a reater likelihood that the factor price change will occur before a specified time. As the following proposition indicates, an increase in the hazard rate results in a decrease in the optimal fuel-capital ratio.

Proposition 5 : If $s = 0$ and $\tau = 0$, $d\gamma^*/dk = 0$. If $s > 0$ or $\tau > 0$, $d\gamma^*/dk < 0$.

Proof : Implicit differentiation of (3) yields

$$\frac{d\gamma^*}{dk} = -(-(1 - e^{-r\tau})\varphi_1 \frac{\partial M_2}{\partial \gamma} + e^{-r\tau} \frac{d\pi_3}{d\gamma})/\frac{\partial^2 V}{\partial \gamma^2}$$

$$= -(r\varphi_1 \frac{\partial M_1}{\partial \gamma}/k)/\frac{\partial^2 V}{\partial \gamma^2}.$$

From Proposition 4 if $s = 0$ and $\tau = 0$, $\gamma^* = \gamma_1$ and hence $\partial M_1/\partial\gamma = 0$, so $d\gamma^*/dk = 0$. If $s > 0$ or $\tau > 0$, $\gamma^* < \gamma_1$. Consequently, $\partial M_1/\partial\gamma < 0$, and $d\gamma^*/dk < 0$. ∎

When the length of the processing period is positive, an increase in the hazard rate increasesthe expected fuel cost relative to the capital cost, and hence, the firm decreases its fuel capital ratio.

IV. The Effect on γ^* of τ and s

In order to obtain a further characterization of the possible bias in the choice of technology resulting from the revenue requirements approach, the effect of the length of the processing period must be determined. The following proposition indicates that the fuel-capital ratio γ^* chosen by the firm is an increasing (constant) (decreasing) function of τ as γ^* is less than (equal to) (greater than) the constant output efficient ratio γ_a.

Proposition 6 : For $0 < k < \infty$, $d\gamma^*/d\tau \underset{>}{\overset{<}{=}} 0$ as $\gamma^* \underset{<}{\overset{>}{=}} \gamma_a$.

Proof : Implicit differentiation of (3) indicates that

$$\text{sign}\ \frac{d\gamma^*}{d\tau} = \text{sign}\ [-d\pi_3/d\gamma - \varphi_1 \partial M_2/\partial\gamma\ ]\Big|_{\gamma = \gamma^*} \tag{8}$$

Solving (3) for the term in brackets indicates that

$$\text{sign}\ \frac{d\gamma^*}{d\tau} = \text{sign}\ [-\tau \frac{\partial M_1}{\partial \gamma_1} - k \frac{\partial M_2}{\partial \gamma}\ ]\Big|_{\gamma = \gamma^*} \tag{9}$$

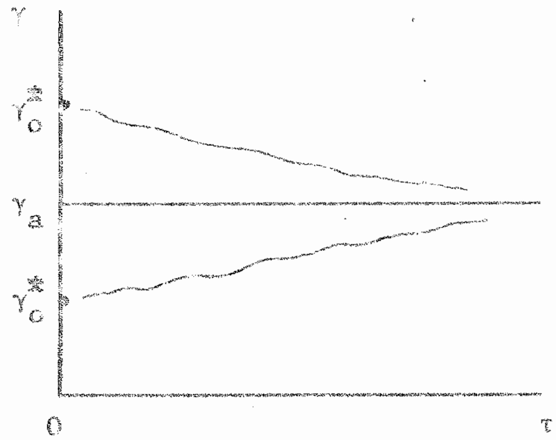
Convexity of the unit cost function M_i and the definition of γ_a imply that the term in brackets is negative (zero) (positive) as $\gamma^* >$ (=) (<) γ_a.∎

As an intuitive interpretation of this result note that as the length of the processing period increases the relative importance of the cost of supplying the output $Q(P_1)$ during the processing period increases, and the impact of γ on π_3 is delayed and hence diminished. The effect of τ on γ^* thus depends on the magnitude of these two impacts at the margin. When $\gamma^* > \gamma_a$, comparison of (8) and (9) implies that

$$-\frac{d\pi_3}{d\gamma} - \varphi_1 \frac{\partial M_2}{\partial\gamma} = -\frac{d\pi_3}{d\gamma} + \frac{\partial\pi_2}{\partial\gamma} < 0 .$$

Since $d\pi_3/d\gamma \leq 0$ from Proposition 4, and $\partial\pi_2/\partial\gamma < 0$ when $\gamma^* > \gamma_a > \gamma_2$, the reduction in the processing period cost obtained through a decrease in γ^* outweighs the gain $(-\frac{d\pi_3}{d\gamma})$ in post-adjustment profit that could be obtained by increasing γ^*. An analogous interpretation holds for $\gamma^* < \gamma_a$. Letting γ_o^* denote the solution to (3) for $\tau = 0$, the result in Proposition 6 is summarized in Figure 2.

Figure 2



Given the result of Proposition 6, the effect of the length of the processing lag on the optimal fuel-capital ratio depends on the relationship between γ_o^* and γ_a. For $\tau = 0$, (3) is

$$-r\varphi_1 \frac{\partial M_1}{\partial \gamma} + k \frac{d\pi_3}{d\gamma} = 0.$$

Defining $Z(s,\gamma) = -r\varphi_1 \frac{\partial M_1}{\partial \gamma} + k \frac{d\pi_3}{d\gamma}$, Proposition 4 implies that $Z(0,\gamma) = -r\varphi_1 \frac{\partial M_1}{\partial \gamma}$, and that

$$Z(0,\gamma^*) = Z(0,\gamma_1) = 0.$$

Consequently, at $s = 0$ and $\tau = 0$, $\gamma_o^* = \gamma_1 > \gamma_a$, so $d\gamma^*/d\tau < 0$. From part (b) of Proposition 3, $\gamma^* > 0$ and $\lim_{\tau\to\infty} \gamma^* = \gamma_a$ which agrees with Proposition 6. If for some $s > 0$, $\gamma_o^* < \gamma_a$, an increase in τ will increase the optimal fuel-capital ratio. Consequently, it is necessary to investigate the relationship between the allowed excess rate of return and γ_o^*.

As a function of s

$$\frac{d\gamma^*}{ds} = - \; ke^{-r\tau} \frac{\partial}{\partial s} \left(\frac{d\pi_3}{d\gamma} \right) \Big/ \frac{\partial^2 V}{\partial \gamma^2}$$

Consequently, $\frac{d\gamma^*}{ds}$ has the same sign as $\frac{\partial}{\partial s}\left(\frac{d\pi_3}{d\gamma}\right)$, which establishes the following proposition.

Proposition 7 : If $\frac{\partial}{\partial s}\left(\frac{d\pi_3}{d\gamma}\right) < (=)\ (>)\ 0$, $\frac{d\gamma^*}{ds} < (=)\ (>)\ 0$.

As indicated in Appendix C, $\frac{\partial}{\partial s}\left(\frac{d\pi_3}{d\gamma}\right)$ is likely to be negative in which case the optimal fuel-capital ratio is a decreasing function of $\dot{s}$.

This however does not necessarily imply that the firm increases its capital stock in the post-adjustment period as s increases. If however $\gamma^* > \gamma_2^s$, a combination of Proposition 3 and 7 reveals that an increase in s reduces the price P_2 and hence with an increased output and a smaller fuel capital ratio more capital is employed. This is in contrast to the result in the Averch-Johnson model as demonstrated in Proposition 5 of Baumol and Klevorick (1970). If $\gamma^* < \gamma_2{}^s$ and γ^* decreases as s increases, the price P_2 increases, and the change in the capital stock K_3^* is given by

$$\frac{dK_3^*}{ds} = \frac{d}{ds}\left(\varphi_2 Q(P_2)\right)g(\gamma^*)) = (\varphi_2' Q_2' g(\gamma^*)\ \frac{dP_2}{d\gamma} + \varphi_2 g'(\gamma^*))\ \frac{d\gamma^*}{ds} \quad .$$

The sign of this expression is ambiguous in general, so only the following result can be stated.

Proposition 8 : If γ^* is a decreasing function of s when $\gamma^* > \gamma_2^s$, the optimal capital stock is an increasing function of s.

Given the result established in Proposition 7, it is now possible to complete the characterization of the effect of τ on γ^*. If marginal post-adjustment profit $(d\pi_3/d\gamma)$ is decreasing in s, then the following lemma results (see Appendix B).

Lemma : If $\partial[d\pi_3/d\gamma]/\partial s < 0$ with $0 < k < \infty$ and $P_2 > P_1$, there exists an s_a such that $\gamma_o^* \gtreqless \gamma_a$ if $s \lesseqgtr s_a$.

Using this result with Proposition 5 yields

Proposition 9 : If $\partial[d\pi_3/d\gamma]/\partial s < 0$ with $0 < k < \infty$ and $P_2 > P_1$, then

$$\frac{d\gamma^*}{d\tau} \lesseqgtr 0 \text{ for all } \tau \text{ as } s \lesseqgtr s_a,$$

and, for $s \lesseqgtr s_a$, $\gamma^* \gtreqless \gamma_a$.

Proof : The result that $\frac{d\gamma^*}{d\tau} \lesseqgtr 0$ as $s \lesseqgtr s_a$ is immediate from Proposition 7. Since $\gamma_o^* > \gamma_a$ if $s < s_a$ and $\frac{d\gamma^*}{d\tau} < 0$ if $s < s_a$, $\gamma^* > \gamma_a$ for all τ. Similar arguments hold for $s = s_a$ and $s > s_a$.

It remains to compare the fuel-capital ratio γ^* that the firm will choose under revenue requirements regulation with the efficient ratio $\gamma_o = \gamma_o(\tau, P_1, P_2)$ that minimizes the output resulting with revenue requirement regulation. For the case in which $s = 0$, $d\pi_3/d\gamma = 0$ from (7), and (3) reduces to

$$-r\varphi_1 \frac{\partial M_1}{\partial \gamma} - k(1 - e^{-r\tau}) \frac{\partial M_2}{\partial \gamma} = 0. \tag{10}$$

Letting the left side of (10) define a function $T(\gamma)$, (10) is $T(\gamma^*) = 0$. Evaluating T at γ_o from (5) yields

$$T(\gamma_o) = ke^{-r\tau}\varphi_2 \frac{\partial M_2}{\partial \gamma}\bigg|_{\gamma = \gamma_o} > 0,$$

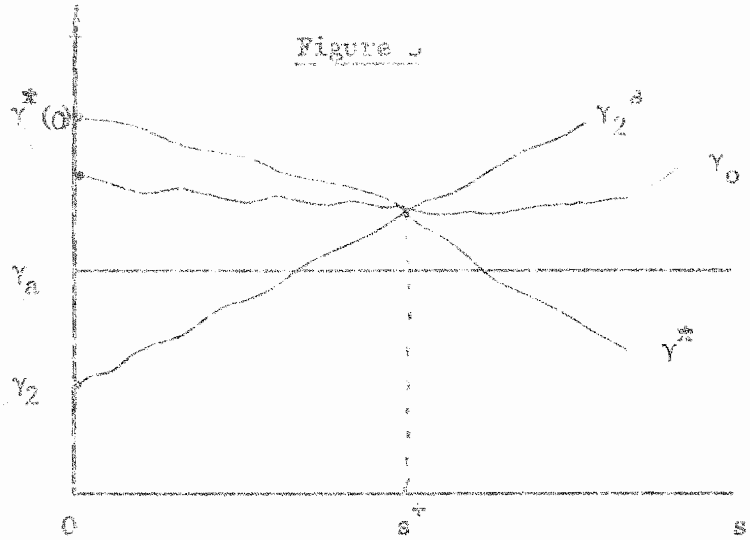
since $\gamma_o > \gamma_2$. Consequently, $\gamma^* > \gamma_o$ at $s = 0$. This results because when $s = 0$ the firm is indifferent to the cost that results after $t + \tau$ and hence place more "weight" on the cost in the $[0,t)$ period. The firm thus employs a higher fuel-capital ratio than is <u>ex ante</u> efficient. Using the result of Proposition 7 yields the following proposition.

Proposition 10 : For $s = 0$, undercapitalization ($\gamma^* > \gamma_o$) results. If $\frac{\partial}{\partial s}\left(\frac{d\pi_3}{d\gamma}\right) < 0$, there exists an s^+ such that $\gamma^* > (=) (<) \gamma_o$ for $s < (=) (>) s^+$.

Proof : Proposition 7 indicates that $d\gamma^*/ds < 0$ under the hypothesized condition. Let $\gamma^*(s)$ denote the solution to (3) as a function of s. Since γ_2^s approaches $(+\infty)$ as $s \to \infty$, there exists an s^+ such that $\gamma^*(s^+) = \gamma_2^s$. Then proposition 3 indicates that for $\gamma^* = \gamma_2^s$, $dP_2/d\gamma = 0$, and as is evident from (3) and (5), $dP_2/d\gamma = 0$ implies that $\gamma^*(s^+) = \gamma_o$. For $s < s^+$, $\gamma^*(s) > \gamma^*(s^+)$ from Proposition 7 and $dP_2/d\gamma > 0$ from Proposition 3. Thus, from Proposition 2, $\gamma^*(s) > \gamma_o$. For $s > s^+$, $\gamma^*(s) < \gamma^*(s^+)$ and $\gamma^*(s) < \gamma_o$.∎

To complete the analysis of the bias caused by revenue requirements regulation, recall from Proposition 1 that γ_o is a strictly increasing function of P_2, so as s increases toward s^+, P_2 decreases and hence γ_o decreases. As s increases above s^+, P_2 increases and γ_o increases. The following Figure 3 summarizes the relationship among γ^*, γ_o, and γ_a.

Figure 3



The bias illustrated in Figure 3 is due to two factors. For $s = 0$, the revenue requirements approach creates an incentive to undercapitalize because the use of more fuel results in a higher adjusted price. As s increases, this effect remains, but in a manner analogous to the Averch-Johnson effect an incentive is created to increase the capital stock. For $s <(>) s^+$ the first (second) effect is the stronger and undercapitalization (overcapitalization) results. As s increases from zero toward s^+, the bias tends to decrease, but as s increases above s^+, the bias increases. Ex ante technical efficiency can be achieved by setting $s = s^+$, where the two incentive problems offset each other.

Analysis of the effect of s on the adjusted price can be used to form a basis for determining the regulator's preferred s. As s is increased toward s^+, the bias is reduced which permits a reduction in price, since $dP_2/d\gamma > 0$ if $\gamma^* > \gamma_2^s$ as indicated in Proposition 3. This is possible because a decrease in cost resulting from increased efficiency outweight the additional return $sK_2(\gamma^*)$ obtained by the firm. Consequently, as s is increased from zero to s^+, both consumers and the owners of the firm are benefited.[11] As s is increased above s^+, however, the bias increases and the adjusted price must increase. Consequently, as s is increased above s^+ consumers are made worse off because of the higher price while the owners of the firm are made better off. This establishes the following result.

Proposition 11 : If $\frac{\partial}{\partial s}\left(\frac{d\pi_3}{d\gamma}\right) < 0$, the regulator should set the allowed excess return at at least the level s^+. The firm then produces the output efficiently from an ex ante viewpoint if $s = s^+$ and overcapitalizes if $s > s^+$. At the optimal fuel-capital ratio $\gamma^*(s)$, the adjusted price P_2 is an increasing function of γ.

The socially-preferred value of s would be that which balances producer plus consumers surplus considerations, but since the focus here is on the effect of price adjustments under revenue requirements regulation, such an optimal s will not be investigated here.

V. Discussion

Under revenue requirements regulation, prices are adjusted so that revenue is provided to cover operating costs, capital costs and an allowed return. Since those costs and the allowed return depend on the technology chosen by the firm, the firm can affect the adjusted price, and thus a moral hazard or incentive proble is created by this type of regulation. For small allowed excess rates of return ($s < s^+$) undercapitalization results while for large s ($s > s^+$) overcapitalization results. A regulator in determining s will prefer to set $s \geq s^+$, since a lower s would create opportunities to both reduce the adjusted price and increase the value of the firm.

For $s \geq s^+$ but less than or equal to value s_a^+ at which $\gamma^*(s) = \gamma_a$ for a given τ, the firm will decrease its chosen fuel-capital ratio (Proposition 5) as the processing period lengthens. This will permit a decrease in price (Proposition 3) which benefits consumers, but because it delays the price adjustment, the owners of the firm are worse off. If s is set above the value s_a^+ an increase in the length of the processing period would increase γ^* and hence increase price while again decreasing the value of the firm. In that case the regulator would prefer to decrease τ until $\gamma^*(s) = \gamma_a$. Consequently, the optimal regulatory policy would be to set s such that $s_a^+ \geq s \geq s^+$ for any τ. Then, a reduction in the length of the processing period would benefit the owners of the firm at the expense of consumers.

A more fundamental aspect of regulatory policy is the choice between price adjustments made through administrative rate review using a revenue requirements approach or through an automatic adjustment mechanism. A mechanism such as that used to adjust prices for the Public Service Company of New Mexico would have similar effects on the choice of technology to the extent that adjustments are based on the revenue requirements approach. Adjustment mechanisms such as the fuel adjustment clauses used for electric utilities however are quite different, since the price adjustment equals the change in the average cost of fuel per unit of output. As indicated by Baron and De Bondt (1978a), a fuel adjustment clause induces a firm to choose a fuel capital ratio that is greater than the ratio that minimizes expected cost at the corresponding output levels. This bias toward undercapitalization can be reduced by increasing the "collection lag", the time between the factor price change and the price adjustment, but the bias remains. Unfortunately, a welfare comparison between these two alternative approaches does not appear possible at the level of generality used in the analysis presented here.

APPENDIX A.

Rate Case Decisions for States Without FAC's, 1/1/76-3/31/77

State and Utility	Application Date	Date of Final Order	New Rates Effect ve	Approximate lag in Month	Interim Rates In Ei ect
Nevada					
Nevada Power Co.	4/30/76	10/28/76	10/30/76	6	no
Sierra Pacific Power Co.	9/20/76	3/14/77	3/22/77	6	no
Nevada Power Co.	11/7/75	4/14/76	4/20/76	5 1/2	no
Sierra Pacific Power Co.	12/1/75	6/3/76	6/3/76	6	no
Montana					
Montana-Dakota Utilities Co.	4/18/75	11/10/76	12/15/76	7	yes as o 3/11/76
Pacific Power & Light Co.	7/10/74	3/3/76	4/1/76	9	no
Oregon					
Portland General Electric Co.	11/26/75	9/1/76	9/3/76	9	no
Pacific Power & Light Co.	2/20/76	12/17/76	12/20/76	10	no
California Pacific Utilities Co.	10/28/75	3/25/76	3/30/76	5	no
Idaho Power Co.	7/22/74	settled in court	1/20/76	-	no
Idaho					
Washington Water Power Co.	2/17/76	11/12/76	1/21/77	11	no
Pacific Power & Light Co.	4/20/76	8/3/76	8/13/76	4	no
Utah Power & Light Co.	9/9/75	4/28/76	5/1/76	8	yes as o 1/1/76
Idaho Power Co.	5/30/75	1/14/76	1/28/76	8	no
Wyoming					
Pacific Power & Light Co.	1/5/76	7/16/76	7/27/76	8	no
Utah Power & Light Co.	9/9/75	3/2/76	3/11/76	6	no
Washington					
Pacific Power & Light Co.	3/19/76	12/29/76	1/11/77	10	no
Washington Water Power Co.	2/17/76	12/23/76	1/21/77	11	no
Puget Sound Power & Light Co.	1/2/76	10/8/76	10/9/76	9	no
Utah					
Utah Power & Light Co.	9/5/75	3/4/76	3/5/76	6	yes as o 2/1/76
Utah Power & Light Co.	10/30/76	2/28/77	3/1/77	4	no

Source : Edison Electric Institute, Electric Rate Case Decision Data

APPENDIX B

Proof of the Lemma : When γ^* implicitly defined by (3) as a function τ is a smooth (continuously differentiable) and monotone function, it will be increasing, constant, or decreasing in τ depending on whether $\gamma^*\big|_{\tau = 0}$ is smaller, equal, or greater than $\lim_{\tau\to\infty} \gamma^* = \gamma_a$. To see how $\gamma^*\big|_{\tau = 0}$ compares with γ_a, evaluate

$$\frac{\partial V}{\partial \gamma}\bigg|_{\substack{\tau = 0 \\ \gamma = \gamma_a}} = k\,\frac{d\pi_3}{d\gamma} - r\,\varphi_1 \partial M_1/\partial\gamma = k\left[\,\frac{d\pi_3}{d\gamma} + \varphi_1\,\frac{\partial M_2}{\partial\gamma}\,\right] \equiv Y(s),$$

noting (5) and the dependence of $d\pi_3/d\gamma$ on s. Given the assumed concavity of V it is clear that $\gamma^*\big|_{\tau = 0} \gtreqless \gamma_a$ as $Y(s) = 0$. Recalling (3) reveals :

$$Y(0) = k[-\varphi_2 \partial M_2/\partial\gamma \;+ \varphi_1 \partial M_2/\partial\gamma]_{\gamma_a} > 0 \text{ for } \varphi_1 > \varphi_2 \text{ or } P_2 > P_1,$$

noting that $\partial M_2/\partial\gamma > 0$ since $\gamma_a > \gamma_2$ as shown in Proposition 1. Substituting $\partial P_2/\partial\gamma$ from (6) in Y, yields

$$\lim_{s\to\infty} Y(s) = \lim_{s\to\infty} k\left[\frac{\partial\pi_3}{\partial P_3}\left(\frac{\varphi_2 \partial M_2/\partial\gamma + \varphi_2 s g'}{\partial\pi_3/\partial P_3 - \varphi_2{}' Q_2{}' s g}\right) - (\varphi_2 - \varphi_1)\partial M_2/\partial\gamma\right] = -\frac{\infty}{\infty}$$

since $g' < 0$. By application of l'Hopitals rule, however :

$$\lim_{s\to\infty} Y(s) = k\,\frac{\partial\pi_3}{\partial P_3}\left(\frac{\varphi_2 g'}{-\varphi_2{}' Q_2{}' g}\right) < 0$$

Moreover, $dY/ds = k\,\frac{\partial}{\partial s}\left[\frac{d\pi_3}{d\gamma}\right] < 0$ by supposition. Thus Y is positive for $s = 0$, and decreases as s increases towards some negative value. Y will therefore become zero for some unique positive value of s designated s_a. For $0 \leq s < s_a$, $Y(s) > 0$

and $\gamma^*|_{\tau = 0} > \gamma_a$. For $s > s_a$ the reverse applies. With $s = s_a$, $Y'(s) = 0$ and $\gamma^*|_{\tau = 0} = \gamma_a$.

APPENDIX C

Analysis of $d\gamma^*/ds$

The sign of $d\gamma^*/ds$ is the same as the sign of $\frac{\partial}{\partial s}\left(\frac{d\pi_3}{d\gamma}\right)$. Intuitively, an increase in s increases the marginal allowed return per unit of capital, and the firm prefers to increase its capital input in response to this incentive. This induces the firm to reduce its fuel-capital ratio for a fixed P_2. The increase in s, however, necessitates an increase in P_2 which dampens demand and hence reduces the required inputs. When the magnitude of the first effect is greater than the magnitude of the second effect, γ^* decreases in s.

Evaluating with P_2 viewed as a function of s and γ yields

$$\frac{\partial}{\partial s}\left(\frac{d\pi_3}{d\gamma}\right) = \frac{\partial}{\partial s}\left(\frac{\partial\pi_3}{\partial P_2}\frac{\partial P_2}{\partial\gamma} + \frac{\partial\pi_3}{\partial\gamma}\right)$$

$$= \frac{\partial^2\pi_3}{\partial P_2{}^2}\frac{\partial P_2}{\partial s}\frac{\partial P_2}{\partial\gamma} + \frac{\partial\pi_3}{\partial P_2}\frac{\partial^2 P_2}{\partial\gamma\partial s} + \frac{\partial^2\pi_3}{\partial\gamma\partial P_2}\frac{\partial P_2}{\partial s}$$

$$= \left(\frac{\partial^2\pi_3}{\partial P_2{}^2}\frac{\partial P_2}{\partial\gamma} + \frac{\partial^2\pi_3}{\partial\gamma\partial P_2}\right)\frac{\partial P_2}{\partial s} + \frac{\partial\pi_3}{\partial P_2}\frac{\partial^2 P_2}{\partial\gamma\partial s} \tag{B1}$$

The term $\partial P_2/\partial\gamma$ is given in (6) and

$$\frac{\partial P_2}{\partial s} = \frac{\varphi_2 g}{\partial\pi_3/\partial P_2 - s\varphi_2{}'Q_2{}'g} > 0,$$

when regulation is effective. Also,

$$\frac{\partial^2 P_2}{\partial\gamma\partial s} = \frac{\varphi_2 g'\frac{\partial\pi_3}{\partial P_2} + \varphi_2{}'Q_2{}'g\varphi_2\frac{\partial M_2}{\partial\gamma}}{(\partial\pi_3/\partial P_2 - s\varphi_2{}'Q_2{}'g)^2},$$

which is negative when regulation is effective if $\gamma^* \geq \gamma_2$ (since $\partial M_2/\partial\gamma$ is then positive). The last term $(\partial\pi_3/\partial P_2)(\partial^2 P_2/\partial\gamma\partial s)$ is then negative if $\gamma^* \geq \gamma_2$. Since π_3 is concave in P_2 and

$$\frac{\partial^2 \pi_3}{\partial\gamma\partial P_2} = -\varphi_2' Q_2' g' < 0,$$

the expression in parentheses in (B1) is negative if $\partial P_2'/\partial\gamma$ is nonnegative. From Proposition 3 $\partial P_2/\partial\gamma \geq 0$ if $\gamma^* \geq \gamma_2^s$, which is likely to be the case for small values of s. Thus, for small s,

$$\frac{\partial}{\partial s}\left(\frac{d\pi_3}{d\gamma}\right) < 0, \text{ and } d\gamma^*/ds < 0.$$

Footnotes

* This material is based upon work supported by the National Science Foundation under Grant No. SOC 77-07251.

1. Joskow (1974) used the term processing lag in his study of commission behavior.

2. Also see Baumol and Klevorick (1970).

3. Kendrick (1975) discusses other automatic adjustment processes.

4. These clauses are used widely in the U.S. (see U.S. Senate (1976)) and in some European countries as well (Price Commission (1978), Eurostat (1977), De Bondt (1978), and Müller and Vogelsang (1978)).

5. As Nickell (1977, p. 250) states : "The idea here is that firms are often in the position of having a fairly good idea what is going to happen but are rather uncertain when". Uncertainty about the size of the factor price change is treated for fuel adjustment clauses by Baron and De Bondt (1978a).

6. Subsequent results are unaltered when the duration of the processing lag is uncertain, or has a certain and an uncertain part, and the probability of a price revision by a date following the factor price change is exponentially distributed.

7. Since $c_2 > c_1$, the price P_2 is greater than P_1, and hence, less capital and fuel are employed than with P_1. The assumptions on the technology of the firm imply that capital is reversible or that capital depreciates at a sufficient rate that additions are required to the capital stock at the price P_2.

8. Only prices P_2 below the price P_n that would be set in the $[t + \tau, \infty)$ period by an unconstrained monopolist will be considered. If P_n and γ_n denote the optimal price and fuel-capital ratio in that case, define the monopoly excess rate of return s_n by

$$s_n = \frac{P_n Q(P_n) - \varphi(Q(P_n))(c_2\gamma_n g(\gamma_n) + vg(\gamma_n))}{\varphi(Q(P_n))g(\gamma_n)} .$$

The firm can thus not earn an excess rate of return s_n in the $[t + \tau, \infty)$ period, so only $s \leq s_n$ will be considered.

9. Growth and technological change are not incorporated into the model in order to permit a focus on the choice of technology and the method used for the adjustment of price.

10. In our notation by solving $\max_{\gamma} [(1 - e^{-r\tau})\pi_2 + e^{-r\tau}\pi_3]/r$ subject to (1).

11. Recall that it is assumed that γ^* is a decreasing function of s.

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